Chaos Control by Directly Modulated Opto Electronic Feedback in Semiconductor Laser

ALRABA.H.EISA
Laser Institute, Sudan University of Science and technology, Khartoum, the Sudan

SORA. F. ABDALAH
Nonlinear dynamics and complex systems Istituto Nazionale di Ottica, Largo E. Fermi 6, 50125, Florence, Italy

WAFAA.S.ABDULRAHMAN
Laser Institute, Sudan University of Science and technology, Khartoum, The Sudan

KAIS A.AL NAIMEE
CNRIstituto Nazionale di Ottica, INO Largo E. Fermi 6, 50125 Florence, Italy

Abstract: **Nonlinear dynamic behavior of a directly modulated delayed optoelectronic feedback semiconductor laser has been studied numerically. The variation of small window of modulation current with the delayed optoelectronic feedback produces chaotic behavior of the laser output. The dynamics is completely determined by the variation of the injecting modulated amplitude (A). The chaotic spiking was observed at (A = 0.060). Excitability of the laser diode under directly modulation current with GHz was demonstrated by bifurcation diagram so the modulation amplitude is sensitive in output dynamic of the laser diode.**

Keywords: **Delayed feedback; Chaotic; Periodic modulation; Nonlinear Dynamics;**

I. INTRODUCTION

Significance of chaotic dynamics in semiconductor lasers receive great attention in the near past decades, due to the applicability of chaotic synchronization of such systems in the field of optical secure communication. This theory was proven by several research groups[1,2,3]. Semiconductor lasers are generally very stable systems when operated with only a Dc bias current. By inclusion additional degrees of freedom to the system dynamic instabilities are induced. Involving external optical injection to the system produce different chaotic outputs [4, 5]. Producing optical feedback [6], direct current modulation [7]. And delayed optoelectronic feedback are the methods of generation chaotic optoelectronic feedback[8].

The conventional method of producing ultra-short pulses is positive delayed optoelectronic feedback [9] from semiconductor lasers. The dynamics of semiconductor lasers with direct current modulation widely studied [10]. It has already been proved that the effect of mode gain reduction occurring due to nonlinear processes is suppression of chaotic dynamics [11]. Production chaotic dynamics by using bidirectional coupling configuration between two such lasers is found [12]. A strong current modulation combined with positive delayed optoelectronic feedback is found to generate chaotic dynamics and bi stability in semiconductor lasers[13].The effect of such a combination in inducing chaotic dynamics through a quasi-periodic route in quantum-well lasers also has been studied [14]. The directly modulated semiconductor lasers with GHz modulation are the most preferred light source in the optical communication systems. A widely investigated topic is chaotic synchronization of two such lasers because of its applicability in optical secure communication [15]. The nonlinear gain reduction for (InGaAsP) lasers used in optical communication systems is very strong and its direct consequence on the dynamics of such lasers suppress of chaotic outputs. A significant role in modeling semiconductor laser dynamics is that the dynamic response of semiconductor laser strongly depends on the nonlinear gain [16]. The results of numerical investigations on the effect of a delayed optoelectronic feedback on the dynamics of lasers

Diode was illustrated [13]. The study was undertaken to find out the possibility of obtaining chaotic outputs from Laser Diode under small values of perpetrated modulated amplitudes. The optoelectronic feedback scheme has the advantage of ease of implementation, as it is insensitive to the optical phase of the output intensity. Therefore the effects of negative delayed optoelectronic feedback schemes were investigated. The results reveal that in the range of normal estimates of nonlinear gain reduction factor for such lasers as suggested by Agrawal [10], only a strong negative delayed optoelectronic feedback is efficient in producing chaotic output. The present work suggested the effect of small modulated amplitude to produce the nonlinear dynamics behavior on semiconductor laser output and the corresponding simulation model is established in terms of dynamical time series, frequency spectrum and phase portraits; the influence of amplitude modulation on the nonlinear behaviors of the considered system is investigated in detail.

II. DYNAMICAL MODEL OF THE SEMICONDUCTOR LASER

The dynamics of the photon density X and carrier density Y is described by the usual single-mode semiconductor laser rate equations [13, 19] appropriately modified in order to include the AC-coupled feedback loop and for numerical and analytical purposes, it is useful to write rate equations in dimensionless form [13, 19]

$$x = x(y - 1) \qquad (2.1a)$$

$$y = (\gamma)((\delta 0) - y + f(z + x) - xy) \qquad (2.1b)$$

$$z = -(z + x) \qquad (2.1c)$$

Considering a closed-loop optical system, consisting of a LD with directly modulated AC-coupled nonlinear optoelectronic feedback (Fig.1). The output light is sent to a photo detector producing a current proportional to the optical intensity. The corresponding signal is sent to a variable gain amplifier characterized by a nonlinear transfer function, $f(w + x) \equiv \alpha (z + x)/(1 + s(z + x))$ and then feedback to the injection current of the LD. The feedback strength is determined by the amplifier gain, Al Naimee model [13].

III. DIRECT PERIODIC MODULATION CURRENT

After modification of rate equations, the model predicts unstable behavior. The transition between chaotic and periodic states was also investigated. The effect of periodic modulating injection current on the chaotic attractors using the same theoretical model by adding the perturbation term and analyzed. The output of the system will be chaotic. There are several possibilities to accomplish these conditions [20]. The simplest one is by modulating the injection current periodically with a modulating frequency (F)(about1GHz in the model).

The injection modulated current in the pumping term (H)equations (2.1c) has to be replaced by a periodic modulated current. The equation for the input current will be modified as follows.

$$z = -(z + x) - (1 + H) * x \qquad (3.1)$$

Where(H)is periodic modulated current equal to.

$$H = A * \sin(2 * \Pi * f * t) \qquad (3.2)$$

(A, f) are the amplitude and frequency of the perturbation.

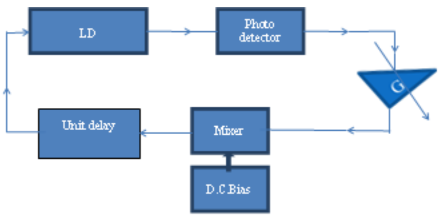


Fig.1. Sketch of the experimental setup for LD

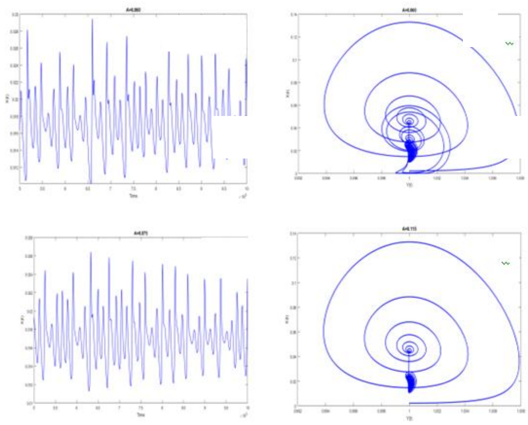
IV. RESULTS AND DISCUSSION

The rate equations (2) are solved numerically using the fourth order Runge-Kutta method with 0.3 micro second step time sizes. The parameter values used in the simulations are assigned as x0=0.0022, y0=1,z0=0.005,γ=0.001, δ= 1.0170, S=11, α=1,

ϵ=2 ∗ 10−5, f=1 ∗ 109Hz.

The injection parameters, i.e., the amplitude of modulation current (A), and modulation frequency,(F), have been chosen carefully. The dynamic time series of the system began by chaotic state and a period doubling route to periodic state occurring in the vicinity of the turning point. (Fig. 2) shows the time series, the corresponding attractors. (Fig.3) describe the FFT for different modulated amplitude (A) values. Fig.2 (A, a) corresponds to the chaotic state. Here, we choose (A = 0.060) as an example, in which the signatures of chaos, the broadened spectrum, and the random distribution in the phase portrait, are observed. Fig.2 (B, b) and (C ,c) represent the quasi chaotic state by increasing the modulation amplitude (A=0.075 till 0.115) the state is converted from the quasichaotic state to the spiral fixed point behavior is shown in Fig. 2(D, d).

It is seen (clear) that, the laser outputs periodically and the phase portrait shows a closed curve when we increasing (A=0.199).Further, there has a prominent frequency component in the frequency domain corresponding to the fluctuation frequency of the laser output.



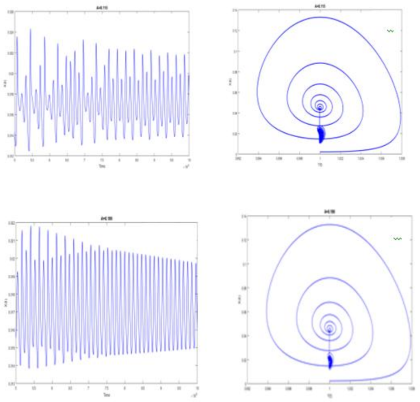


Fig.2: Numerical simulations of the model equations First column represent time series and second columnrepresent phase space the light intensity for selected amplitude(a) A = 0.06 (b) A = 0.075 (c) A =0.115 (d) A = 0.199. The other parameters are:x_0 = 0.0022,y_0 = 1,z_0 = 0.005,γ = 0.001, δ = 1.0170, S = 11, α = 1,□= 2 × 10^{-5},F = 1 × 10^{9} Hz.

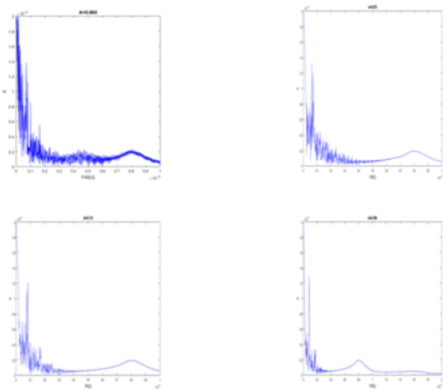


Fig.3Fourier transform for the light Intensity for selected amplitude. The parameter values are set as Fig.2.

Initial Hopf bifurcation. As (A) approaches the turning point (when its value becomesles than 0.081) the chaotic amplitude fluctuationsare sufficiently less to trigger fast dynamics.This results in an erratic-sensitive toinitial condition sequence of homoclinic spikes ontop of a chaotic background.

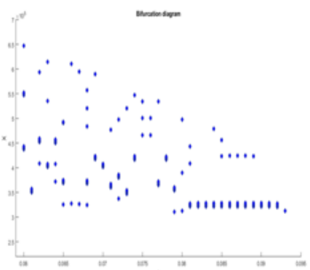


Fig. 4: Bifurcation diagram for the model equations. The parameter values are set as Fig.2.

V. CONCULOSION

Generation of the chaotic spiking by using optoelectronic feedback with constant bias injunction current was numerically studied. A delayed optoelectronic feedback diode laser is employed to study the ability of obtaining chaotic output from directly modulated semiconductor laser under GHz modulation. The results showed the effect of small window modulation amplitude on the output dynamics when all other control parameters are kept constant at the chaotic operating condition. Excitability of the system by bifurcation diagram was observed so the modulation amplitude is sensitive in output dynamic. The optoelectronic delayed feedback laser diode can be controlled to get at a given nonlinear state, such as the single periodic, periodic doubling, quasi chaotic, chaotic by choosing (A) and (f) properly.

VI. REFRENCES

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